

History of solar wind and space plasma physics revisited

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Abstract

A paper published by Scottish geophysicist J.A. Broun in 1858 contained several pioneering and remarkable ideas in solar-terrestrial physics. He could anticipate more or less correctly the nature and origin of solar wind, solar magnetic fields, sunspot activity and geomagnetic storms in the middle of the 19th century. Broun applied the experimental results of the behaviour of ionised gases in discharge tubes for the first time to Space Physics which may be considered as the beginning of the astrophysical plasma physics. In this context he attempted to explain the plasma interactions of solar wind with the comet tails and earth's magnetosphere. Most of the postulates or hypotheses put forward by Broun in 1858 and later in 1874 was rediscovered during the 20th century, after the advent of Space age.

Keywords: Solar wind, Plasma physics, Solar magnetic fields, Magnetosphere, Comet tails

1. Introduction

Emergence of physical ideas of solar wind and space plasma physics during the 20th century significantly contributed to our current knowledge of planetary sciences. The quest for the causes of aurora and associations of the geomagnetic variations with solar phenomena like sunspots inspired the development of solar-terrestrial physics in the 18th and 19th centuries (Parker, 1989). Kristian Birke-land's Terrella experiments (1896–1913) were considered as the first study of that kind in space plasma physics (Rypdal and Brundtland, 1997). Ideas of transient particle emission from the Sun were developed since late 19th century (Goldstein, 1881; Mitra, 1952). However continuous solar wind flow from the Sun were actively considered by space physicists only during early 1950's (Biermann, 1951). We need to revisit the present history of solar wind and space plasma physics when we consider the scientific contributions of John Allan Broun during the 19th century.

John Allan Broun, the Scottish geophysicist and as-

tronomer is well known for his discoveries of semi-annual variations in geomagnetic activity (Broun, 1848) and solar sources of recurrent geomagnetic storms before Maunder (Broun, 1876). Broun served as the director of Matherstom magnetic observatory in Scotland during the years 1842–1848 and Maharaja's observatory in Trivandrum during the years 1852–1865 (Clerke, 2004). During his service in Trivandrum (situated near magnetic dip equator) J.A. Broun wrote a remarkable paper in December 1857 which was published in *Philosophical Magazine* as a letter next year (Broun, 1858). This was one hundred years prior to the publication of the hydrodynamic theory of the solar wind (Parker, 1960).

In this article we will discuss first about the pioneering ideas of Broun contained in the above paper about the nature and origin of solar magnetic fields and sunspot activity at a time when solar physics was just emerging as a research discipline. We will also explain how Broun perhaps opened the studies on astrophysical plasma physics when he applied the experimental results of electricity and magnetism (gas discharge tube experiments) to space physics.

The nature of solar wind type medium filling the interplanetary space and its interaction with plasma bodies like comets and earth's magnetosphere as envisaged by Broun in his paper (Broun, 1858) during the middle of 19th century will be then discussed. It is interesting to find that experimental confirmation to Broun's postulates/hypotheses in 1858 and later in 1874 could be possible only during the second half of 20th century with the advent of space age.

2. Broun's ideas of solar magnetic fields and sunspot activity in the year 1858

After the discovery of sunspot cycle (Schawabe, 1844) the attempts to connect sunspot activity with geomagnetic phenomena was purely statistical or empirical in nature and lacked physical models to support the same. In order to explain certain laws of geomagnetic variations observed in Europe and Trivandrum, Broun proposed some new ideas about sunspot activity and solar magnetic fields with some physical insight in his *Philosophical Magazine* paper (Broun, 1858). The relevant portions from the text of the above paper will be cited below (given within inverted commas). We have given our explanatory notes in the modern scientific perspective for each citation which are numbered serially in the small Roman numerals. The page numbers refers to the original paper of Broun.

(i) "page 94: Does not sun act as a magnet, perhaps as an electromagnet, the currents forming it being within its atmosphere?"

- The origin of solar magnetic fields is due to an electromagnetic induction process involving an electromagnet and currents flowing in the solar atmosphere. This can be considered as an early anticipation of dynamo models of astrophysical magnetic fields by Broun.

(ii) "page 94: Are not the solar spots disruptions of the current due to positions of planets in the plane of its equator?"

- J.A. Broun was one of the earliest proponents of the theory of possible physical connections between planetary dynamics, sunspot activity and origin of solar magnetic fields which was followed by others in the 19th century (De La Rue and Loewy, 1865; De La Rue, Stewart and Loewy, 1872). This is also a topic of current interest (Hung, 2007). Planets in our solar system are known to revolve the sun in orbits situated close (within ten degrees) to the heliographic equator (Novotny and Fairbridge, 1967).

(iii) "page 95: If the sun act as a magnet it is possible from the analogy of our earth, that its magnetic poles will not coincide with the poles of rotation; perhaps even the poles may have unequal forces. In such a case, it might be expected that the fact could be determined from our magnetic observations."

- Broun's remarkable and intuitive perception of the nature of large scale solar magnetic fields. During sunspot minimum and declining phases of the sunspot cycles large scale solar magnetic fields often resembles a tilted dipole configuration (Shultz, 1973; Zirker, 1977). North-south asymmetry in the strength of solar polar magnetic fields and differences in the epochs of reversals in northern and southern helio hemispheres are well documented in the solar-terrestrial literature of recent times (Babcock, 1959; Makarov and Makarova, 1996). Broun's idea of inferring properties of solar magnetic fields from geomagnetic data is also acceptable in the modern context (Lockwood, Stamper and Wild, 1999; Love, Rigler and Gibson, 2012).

3. Beginning of astrophysical plasma physics: Broun's ideas of solar wind and its interaction with comets and earth's magnetosphere.

Studies on the electric discharge lamps and electric arcs (Crowther, 1969; Maecker, 2009) inspired the investigations on the discharge of electricity through rarefied gases in the 19th century (Thompson, 2005). This later contributed to the development of atomic physics and plasma physics. J.A. Broun was perhaps the first physicist to apply the results of discharge tube experiments in electromagnetism to space physics which may be considered as the beginning of astrophysical plasma physics. In this section we will describe about these pioneering ideas of Broun published in his philosophical magazine paper (Broun, 1858). As in the previous section citations of relevant passages on the above paper will be presented here with our brief explanatory notes.

(iv) “page 96: Sir John Herschel, I believe has somewhere suggested electricity as the cause which directs the tail of comets.... Are not comets formed by magnetic gases? Is not the tail of the comet due to the directive action of the solar magnet, the curvature of the tail, sometimes seen, being due to the position of solar magnetic poles relatively to the path of the comet? Is not the condensation of comet, when approaching the sun, a phenomenon similar to those observed by Dr. Faraday and M. Plücker in their recent researches on the action of the poles of a magnet on certain gases or liquids?..”

- Scientists prior to Broun suggested a polar force probably of electrical nature from the sun acting on the comet tails during its passage towards the sun (Mendis, 2006). Broun proposes that the observed changes in the tail of comets may be due to the action of extended solar magnetic fields in the interplanetary space. He considers this phenomena analogous to the behavi-

our of ionised gases like hydrogen in electric discharge tubes under the action of external magnetic fields as observed by scientists of his time like Plücker in Germany and Micheal Faraday in England (Plücker, 1858).

This is an interesting example of the Broun's intuitive guess of the interaction of interplanetary magnetic field (carried by the solar wind) with the cometary plasma at least hundred years prior to the satellite era during which it was experimentally confirmed (Biermann, 1963).

(v) “page 97: Is not the zodiacal light the magnetic aether in a luminous state, repelled by the solar magnetic poles?

Does not zodiacal light revolve around the sun?

If so, what is its period of revolution?

Are not the extent and the intensity of zodiacal light related to the periods of spots as Cassini and Mairan supposed?”

- Scientists of the 19th century invoked the idea of an *ether* type media filling the interplanetary space to felicitate any kind of energy (example: sunlight) or physical action propagating through the same. J.A. Broun also shared a similar idea to explain the physical action of solar magnetic fields on distant objects in interplanetary medium such as cometary plasma. If one assumes an earth like magnetic field existing on the sun with a strength around 0.4×10^{-4} T it will be reduced to 2.5×10^{-17} T near earth by inverse square law variations. Like Mairan (1754) Broun also believed that zodiacal light is a kind of gaseous discharge from the sun. According to him it is a magnetic material filling the interplanetary space and is released from the sun due to repulsive action of the solar magnetic fields. Broun also assumes that such a gaseous discharge co-rotates with

sun implying that is possibly a continuous out-flow from our star. He also suggests that the density of the above interplanetary material (as known from intensity and size variations of the zodiacal light). can possibly change with the phase of the sunspot activity cycle.

(vii) “page 97: From the known action of the sun on gases of comets, may we not infer some action of the sun on the gases forming our own atmosphere?... Should not the sun acting as a magnet on the magnetic gases forming our atmosphere, and by induction on the terrestrial magnet, cause the atmosphere to assume an ellipsoidal form, having the greater axis in or near the plane of equator?... If the form which the atmosphere assumed, under the influence of terrestrial and solar magnets, were some what irregular (as in some figures assumed by magnetic liquids, between poles of a magnet as in M. Plücker’s experiments)...

- Eventhough several models of the possible interactions of solar wind particles with earth’s magnetic field were developed during the first half of the 20th century (see Mitra, 1952, for details) the deformation of the earth’s magnetosphere from the dipole geometry (day side compression and extended magnetic tail) due to interaction with the continuous solar wind flow was not known until the spacecraft age (Kivelson and Russel, 1995). But Broun could anticipate this discovery at least hundred years prior to its experimental confirmation. He could also infer that the physical mechanisms behind interaction of extended solar magnetic fields (carried by the solar wind) with comets and earth’s magnetic atmosphere are identical or similar in nature.

It is well known that search for the physical nature of cathode rays lead to the discovery of

electrons by J.J. Thompson in 1897 (Thompson, 1897). Actually cathode rays was discovered much earlier through pioneering experiments carried by (Plücker, 1858) on the action of external magnetic field on rarefied gases in discharge tubes. The shape of light glows in these discharge tubes (Geisslers tubes) used by Plücker for the above experiments surprisingly resembled the shape of earth’s magnetosphere (see Fig. 1). Plücker’s experimental results served as an inspiration to J.A. Broun to model the interaction of extended solar magnetic fields (propagating through a gaseous *ether* media in interplanetary space as assumed by him) with the earth’s magnetic atmosphere (or magnetosphere). According to Broun the shape of the earth’s magnetosphere is deformed and resembles an ellipsoid with greater axis near the geomagnetic equator.

(viii) “page 95: Is not the case that the magnetic disturbances coexists always with the spots; but it is not impossible that during the *formation* of the spots the disturbance is produced that is to say at the period when the supposed *discharge* of the sun’s electrical atmosphere occurs (words in italics form part of original text).

- Broun makes same comments on the solar origin of geomagnetic storms. He suggests two possibilities to explain the observed association between sunspot activity and magnetic storms. It can be related to the phenomenon of formation of sunspots itself. Another possibility is that magnetic storms in earth occurs when an electrical discharge from the solar atmosphere occurs. The later suggestion of Broun is similar to the model of Goldstein (1881) who assumed particle emission from sunspots as the cause of the observation of aurora on earth.

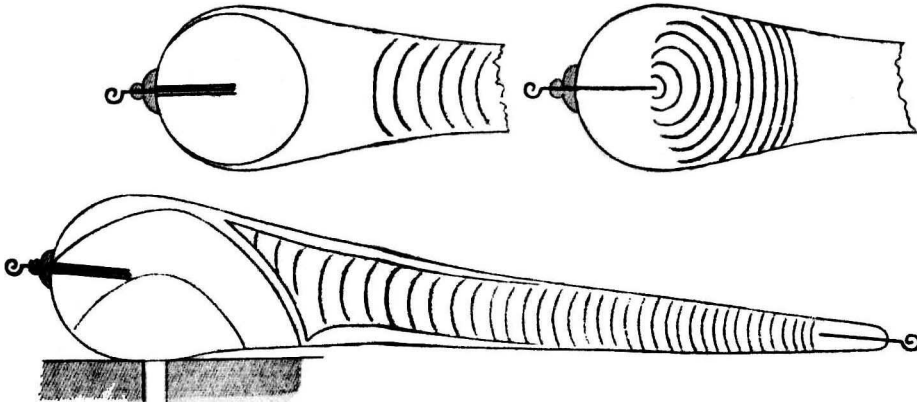


Figure 1: The Geissler tubes and glows shown as fringe type patterns inside the same used by Plücker in his discharge tube experiments (part of plate I of Plücker, 1858)

(ix) “page 94: After a magnetic disturbance there is a diminution of force shown on earth, which remains for some days as if there had been a violent action with the result of loss of energy.”

- Geomagnetic storm occurrences in the mid/low latitudes is characterised by a significant decrease in the horizontal component of the earth’s magnetic field lasting upto 2–3 days during the main phase of such magnetic disturbances. They are now understood to be part of large energy dissipation events in the magnetosphere–ionosphere systems as a consequence of solar wind–magnetosphere energy coupling (Akasofu, 1981). It is quite interesting to find that Broun could anticipate long ago (in 1858) that geomagnetic storms are indeed part of a huge energy dissipation phenomena in the earth environment involving strong or violent physical interactions.

4. Discussion

Several decades prior to the dawn of modern atomic physics and plasma physics, Broun could propose several pioneering ideas in solar-terrestrial physics which were re-discovered during the 20th century (Table 1). J.A. Broun was a versatile genius who could think much ahead of his

time. As a visionary he could find striking similarities between interaction of solar magnetic fields with cometary or magnetospheric plasma and ionised gas behaviour under external magnetic fields in discharge tube experiments. This perhaps opened a new branch of study ‘astrophysical plasma physics’ surprisingly during the middle of 19th century.

Scientists of the 18th century like Mairan (1754) and early 19th century like Cassini suggested that interplanetary space is filled with matter of solar origin and Zodiacal light (now understood to be an optical phenomena in earth’s atmosphere) is visible manifestation of the same. Broun (1858) provided a physical basis to these ideas by proposing that ‘magnetic gases’ are continuously flowing outward from the solar atmosphere to the interplanetary medium by the repulsive action of solar magnetic fields on these gases... Later in 1874 during the discussion of Trivandrum geomagnetic observations he proposed a thermodynamical mechanism of coronal expansion to account for the solar wind outflow from the sun which is cited below (Broun, 1874).

“I believe the facts now certainly connected with solar and lunar magnetic action cannot be explained without the existence of an electric medium similar to through it may be denser than in which light and heat are propagated.

As a footnote: The idea of such a medium was sug-

Table 1: Pioneering ideas of J.A. Broun in 1858 and its rediscovery during the 20th century

Broun's ideas	Rediscovery during the 20th century
1. Nature and origin of solar wind (Broun, 1874, with additions in)	Hydrodynamic theory (Parker, 1960) Satellite observations during 1958–62
2. Sunspot activity: possible connection with planetary dynamics in the solar system	Shuster (1905)
3. Nature of large scale solar magnetic fields:-	
(a) origin due to an electromagnetic induction process in the sun	Dynamo theory of Larmor (1919)
(b) tilted dipole configuration	(Shultz, 1973)
(c) north-south asymmetry in solar polar magnetic fields	(Babcock, 1959)
4. Solar wind and IMF plasma interactions:	
(a) with earth's magnetosphere causing distortion in shape	Explorer satellite observations (Kivelson and Russel, 1995)
(b) with comet tails	Biermann (1963), Neidner and Brandt (1978), Neidner (1982)
5. Geomagnetic storm as a significant energy dissipation phenomena in the terrestrial environment	Solar-wind magnetosphere energy coupling models Akasofu (1981)

gested by Herchel in 1843 (see for eg. Steven Ruskin, 2004). It is quite possible that there may be denser medium around the sun. I have long ago suggested that the zodiacal light is formed in this medium by the passage of electric fluid (*Broun, 1858*). If M. Fayes theory of the repulsive action of solar heat, which blows out the cometary gases so many millions of miles could be assumed the same action should blow off a part of solar gases.”

5. Conclusions

1. John Allan Broun, the Scottish geophysicist could propose several pioneering hypotheses/postulates in solar terrestrial physics which are published in 1858 and 1874.
2. Broun could suggest physical mechanisms for continuous solar wind flow and solar coronal expansion in the above years.
3. Broun was responsible for the beginning of Space Plasma Physics in the middle of 19th century when we applied the experimental results of the behavior ionized gases in discharge tubes to Space physics. He could explain solar wind interactions with comet tails and earth's magnetosphere much before the Space age and dawn of plasma physics. This preceded Birkeland's Terrella experiments in laboratory space physics by at least forty years.
4. Broun's postulates about nature and origin of solar magnetic fields, sunspot activity and geomagnetic storms in 1858 were in agreement with modern findings during the 20th century.

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